Investigation of the beyond-threshold susceptibility in antiferromagnetic $MnCO_3$ and $CsMnF_3$ in parametric excitation of spin waves

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It was observed that the real and imaginary parts of the beyond-threshold susceptibility in antiferromagnetic $MnCO_3$ and $CsMnF_3$ do not depend on the temperature and coincide in order of magnitude with the static susceptibility. The dependences on the static field and on the microwave power agree with the formulas of [7].

A number of recent experimental papers are devoted to parametric excitation of spin waves in antiferromagnets. All deal either with measurements of the critical (threshold) field h_c at which parametric excitation sets in[2–5] and the calculation of the spin-wave damping corresponding to this field, or else to the study of the kinetics of the excitation near the threshold.[6,7]

The behavior of the spin system beyond the excitation threshold is at present not perfectly clear. One of the possibilities of investigating this question is to measure the nonlinear dynamic susceptibility χ, which is produced in the sample at $h > h_c$, which we shall call the "beyond-threshold" susceptibility. The quantity χ can be defined as the coefficient proportionality between the alternating (at the pump frequency ω_p) density of the ferromagnetic moment **m** and the amplitude h of the pump field, at $H \parallel h \parallel 0x$

$$m_x(\omega_p) = \chi h(\omega_p), \qquad \chi = \chi' + i\chi''. \tag{1}$$

The purpose of our study was to investigate the beyond-threshold susceptibility of antiferromagnets with easy-plane anisotropy, namely the collinear antiferromagnet $CsMnF_3$, and the weak ferromagnet $MnCO_3$ in which the Dzyaloshinskiĭ field is $H_D = 4.4$ kOe.[1)]

We used a setup described in detail in[4]. The investigated sample, measuring 2×2×0.3 mm, was glued with BF-4 adhesive to the bottom of a cylindrical resonator with $Q \approx 10\,000$, in the antinode of the magnetic field of the H_{012} mode. The static magnetic field was applied parallel to the high-frequency field in the plane of the sample, which coincided with the basal plane of the crystals.

The beyond-threshold susceptibility $\chi = \chi' + i\chi''$ was determined from the change of the resonance characteristic of the resonator, which occurred when spin waves were parametrically excited in the sample. The change in the natural frequency of the resonator yields information on the value of χ', and the change of the Q (or of the power flowing through the resonator) determines χ'':

$$\chi' - \chi_0 = \frac{2\pi}{\sigma}\,\frac{\omega - \omega_0}{\omega_0},$$
$$\chi'' = \frac{2\pi}{\sigma}\left(\frac{1}{Q} - \frac{1}{Q_0}\right) = \frac{1}{4\pi\sigma Q_0}\sqrt{\frac{P_0}{P} - 1}, \tag{2}$$

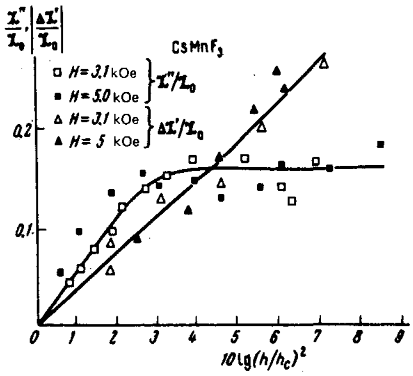

FIG. 1. Dependence of the beyond-threshold susceptibility on the value of the microwave power in $CsMnF_3$ ($\chi_0 = 0.87 \times 10^{-3}$ CGS units/cm³.

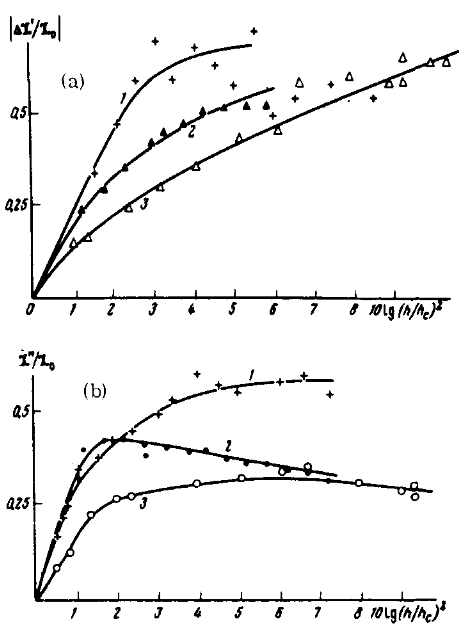

FIG. 2. Dependence of the real part of (a) and of the imaginary (b) of the beyond-threshold susceptibility (1—H = 1.94 kOe, 2—3.46 kOe, 3—4.1 kOe) on the microwave power level in $MnCO_3$ at different values of the static magnetic field. $\chi_0 = 1.36 \times 10^{-3}$ CGS units/cm³.

where

$$\sigma = \int_{V_0} h^2 dv / \int_{V_p} h^2 dv$$

is the filling factor and its order of magnitude is the ratio of the sample volume V_0 to the resonator volume V_r; χ_0 is the susceptibility in the absence of parametric excitation; ω_0, Q_0, and P_0 are the natural frequency, resonator Q, and the power passing through the resonator at $h < h_c$, while ω, Q, and P are the same quantities in the presence of parametric excitation in the sample.

The microwave-power source ($\omega_p/2 = 36$ GHz) was a klystron operating in a slow frequency-sweep regime.

The klystron frequency-sweep rate was chosen such that the time τ of passage through the resonance curve amounted to 2—5 msec. At these and lower sweep rates, the measurement results are independent of τ. At higher sweep rates, χ'' began to decrease with increasing τ. In addition, χ' began to depend on the sweep direction.

The resonator was filled with superfluid helium to prevent overheating of the sample. The microwave signal passing through the resonator was detected with a crystal detector and fed to a two-beam oscilloscope. The microwave field at the sample and the power passing through the resonator were measured by the method described in[4]. To measure the frequency shift of the resonance curve and to measure its half-width with high accuracy, the setup was supplemented with a frequency calibrator based on the Ch-4-8 frequency meter.

It was observed in[5] that two threshold fields, h_{c1} and h_{c2}, exist. The values of χ'' in the microwave-field interval from h_{c1} to h_{c2} were obtained by reducing oscillograms of the type shown in Figs. 2b and 2c of[5].

The errors in the determination of the absolute values of χ' and χ'' were ~30%, whereas the relative errors in one measurement run were 10—15%.

The experiments were performed at a pump frequency $\omega_p/2 = 36$ GHz in the entire range of static fields at which parametric spin-wave excitation in $MnCO_3$ and $CsMnF_3$ was possible at the frequency $\omega_k = \omega_p/2$. The temperature ranged from 1.2 to 2.17 °K. For the investigated quanties $\Delta\chi' = \chi' - \chi_0$ and χ'' we obtained the following results (Figs. 1 and 2):

1) The values of $\Delta\chi'$ and χ'' do not depend on the temperature in the interval 1.7—2.17 °K.

2) The change in the real part of the susceptibility $\Delta\chi'$ is negative in sign, and its absolute value increases monotonically with increasing amplitude h of the microwave field.

3) The imaginary part χ'' of the beyond-threshold susceptibility increases with increasing h, reaches a maximum value χ''_{max} at $(h/h_c)^2 \approx 3$ dB, and then decreases slowly.

4) The quantities $|\Delta\chi'(h \to \infty)|$ and χ''_{max} are close to the linear values of the susceptibility of the high-frequency branch χ_0.

5) The absolute values of $\Delta\chi'$ and χ'' in $MnCO_3$ increase with decreasing static field H. In $CsMnF_3$, the values of $\Delta\chi'$ and χ'' do not depend on H.

The beyond-threshold susceptibility for antiferromagnets with each-plane anisotropy was calculated by Kolganov, L'vov, and Shirokov[7] on the basis of a nonlinear stationary theory.[8] The values of χ obtained by us as functions of the high-frequency and static magnetic fields agree qualitatively with the formulas of[7]. However, the values of χ obtained in experiments are approximately half as large as those predicted by the theory.

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